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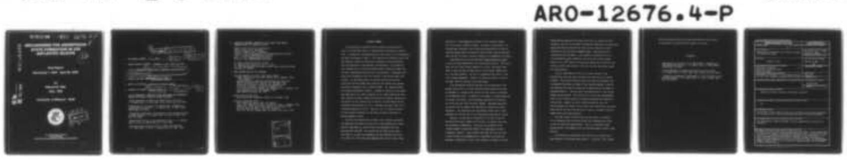

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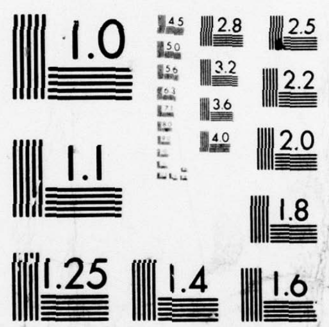

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MECHANISMS FOR AMORPHOUS STATE FORMATION IN ION IMPLANTED SILICON

12

Final Report

(November 1, 1974 - April 30, 1978)

by

Edward B. Hale

May, 1978

University of Missouri - Rolla

U.S. ARMY RESEARCH OFFICE
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7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

"Energy Dependence of Amorphizing Implant Dose in Silicon", J. R. Dennis and E. B. Hale, Appl. Phys. Letters 29, 523 (1976).

"Amorphization of Silicon by Ion Implantation: Homogenous or Heterogeneous Nucleation?", J. R. Dennis and E. B. Hale, Radiat. Effects 30, 219 (1976).

"Crystalline to Amorphous Transformation in Ion Implanted Silicon: A Composite Model", J. R. Dennis and E. B. Hale, J. Appl. Phys. 49, 1119 (1978).

"Damage Depth Profiles in Ion Implanted Silicon", J. P. Sadowski and E. B. Hale, in preparation for J. Appl. Phys.

"Inhibited Amorphization of Silicon in Boron Implantations", C. E. Yates and E. B. Hale, in preparation for J. Appl. Phys.

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Edward B. Hale (Principal Investigator)
John R. Dennis (Ph.D. Candidate)
Joseph P. Sadowski (Ph.D. Candidate)
Claire E. Yates (Undergraduate and Graduate Research Assistant)
Loyd G. Perrymore (Undergraduate Assistant)
Gary J. Seiter (Undergraduate Assistant)
Patrick L. Cole (Undergraduate Assistant)

Dr. Dennis received his Ph.D. in 1976.
Mr. Sadowski will receive his Ph.D. in 1978.
All four undergraduates have done a senior thesis project and have received B.S. degrees.

9. ORAL PRESENTATIONS ON THIS RESEARCH:

One hour seminars (all by Dr. Hale unless noted):
- Wright Patterson Air Force Base, Dayton, Ohio, December, 1976, (Mr. Sadowski).
- National Bureau of Standards, Gaithersburg, MD, June, 1977.
- Kansas State University, Lawrence, KS, September, 1977.
- University of Missouri, Columbia, MO, September, 1977.
- University of Missouri, Rolla, MO, December, 1977.
- U. S. Army Electronics Command, Fort Monmouth, N.J., December, 1977.
- Lord Corporation, Erie, PA, December, 1977.
- ARO, Research Triangle, NC, 1978.

Twenty minute invited talk:
- Small Accelerator Conference, Denton, TX, November, 1978.

Ten minute conference talks:
- APS, Atlanta, GA, March, 1976, (Mr. Dennis).
- Inter. Rad. Damage in Semicond., Dubrovnik, Yugosl., September, 1976.
- Midwest Sol. State Conf., West Lafayette, IN, October, 1976.
- APS, San Diego, CA, March, 1977, (Mr. Sadowski).
- Solar Cell and Rad. Damage, NASA, Cleveland, Ohio, April, 1977.

RESEARCH SUMMARY

This research was concerned with the physical processes which occur in silicon when a wafer is implanted with high doses of various ions. In particular, the amorphization of the crystal by ion implantation has been investigated in detail. The electron spin resonance signal from the amorphous regions has been used to determine various mechanisms which are important to the amorphous transformation. The purpose of this research was to critically examine several theoretical models and the basic understands concerning this transformation. Experiments were specifically designed to test the validity of the various models and concepts. As explained below, our original purpose has been met since both incorrect models were found and other models and concepts have been incorporated into a composite model. Our composite model has created considerable interest. A number of seminars on this model have been given, and reprint requests for our recent publication have been received from many leading universities and research laboratories. The results of this research are of interest to semiconductor device manufactors and designers for use in microwave and other types of ion implanted integrated circuits. They are also of interest because of their possible relevance to the newly discovered techniques of doping amorphous silicon.

One area of confusion that existed in the literature concerned the importance and effects of dose rate on the amorphization process. Specific experiments to test the dose rate dependence have been performed and reported.[1] This publication has definitively shown that there is no dose rate dependence and that amorphization occurs as a result of silicon atom rearrangement about the ion track, often

referred to as heterogeneous nucleation of the radiation damage. Prior to our work a number of papers, including a review paper at an international conference, had claimed that amorphization occurred as radiation damage centers nucleated in regions where they had migrated away from the ion track, a process referred to as homogenous nucleation.

Experiments have also been reported[2] in Applied Physics Letters on the ion energy dependence of the amorphization process. The results show, for ions light in mass compared to silicon, that about three times as many ions must be deposited at a high energy (200keV) than at a low energy (20keV). For ions of comparable mass, there is very little energy dependence. However, for heavy ions about a factor of two fewer ions are required at the high energy.

This interesting variation with mass can be understood if one assumes there exists a critical deposited energy density which must be exceeded in a volume of the lattice for that volume to transform to the amorphous state. In addition, this energy is assumed deposited into atomic collisions, since the energy deposited into electronic collisions does not cause structural damage. Tabulated theoretical values were used to compute the theoretically expected ion energy dependence. The theoretical and experimental results were in good agreement and verified the critical deposited energy density concept.

Recently, we were able to interpret all our data on how the amorphization process changes with ion mass, ion energy, dose rate, and implantation temperature. These data are explained in our "Composite Model" paper[3], which details the importance of several fundamental concepts. These concepts were that the first ion into a region caused only predamage while a subsequent ion caused the amorphous transformation; that it was necessary to exceed a critical

energy density deposited into atomic collisions to induce the transformation; and that at the higher implantation temperatures the deposited energy diffused out from the ion track with the vacancies as they diffused out from the heavily damaged region. When the data was interpreted using the model, it was possible to determine the size of the amorphous region around the ion track, the critical energy density of 6×10^{23} eV/cm^3, the activation energy for diffusion of the vacancy, and that the second or third ion into the same region caused the transformation.

Finally, experimental results on two other aspects of the amorphization have been taken and papers on these results are being prepared. One project focused on depth profiling the implanted layer to determine the extent and depth of the radiation damage. Actually, the amorphous ESR signal is being used to depth profile the amount of amorphous material. From this data, the depth profile of the lattice damage can be obtained. The results for an ion of mass approximately equal to the silicon atom are in excellent agreement with theoretical calculations. However, for both lighter and heavier ions, the measured damage lies nearer to the surface than theoretically predicted. These results are one of the few cases in which a systematic study of damage profile have been measured.

The other project for which data has been taken is concerned with an anomalous dose rate effect which only implanted boron seems to have an inhibiting amorphization. This is an important study because boron is the commonly used ion implanted dopant to make p-type material.

In conclusion, we noted that the results of our research have been reported in three major publications. In addition, nine lengthy

talks and several shorter talks have been delivered, which gives an indication of the quality and interest in our work.

REFERENCES

1. "Amorphization of Silicon by Ion Implantation: Homogenous or Heterogenous Nucleation?", J. R. Dennis and E. B. Hale, Radiat. Effects 30, 219 (1976).

2. "Energy Dependence of Amorphizing Implant Dose in Silicon", J. R. Dennis and E. B. Hale, Appl. Phys. Letters 29, 523 (1976).

3. "Crystalline to Amorphous Transformation in Ion Implanted Silicon: A Composite Model", J. R. Dennis and E. B. Hale, J. Appl. Phys. 49, 1119 (1978).

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The finding in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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Ion implantation; radiation damage; silicon; amorphization; electron spin resonance.

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A summary is given of the results obtained on this grant. Various experiments were performed to better understand the mechanisms which are important to the crystalline to amorphous transformation produced by ion implantation. From these experiments have emerged several important concepts and processes.* These have been reported in several publications and talks, and ~~we have been~~ ~~able~~ to interpret ~~our~~ the results in terms of a composite model for the amorphization transformation.

* it has been possible